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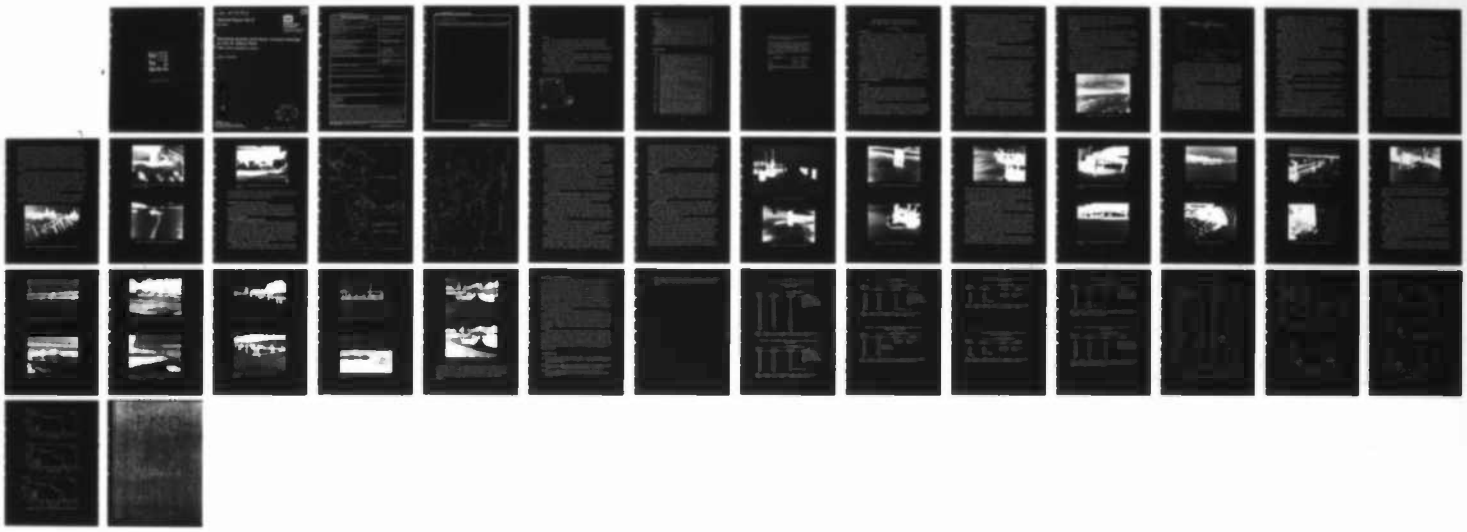

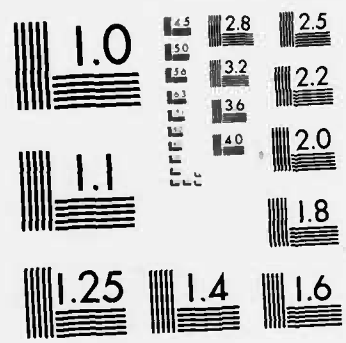

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Special Report 83-15

May 1983

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Shoreline erosion and shore structure damage on the St. Marys River

1980 closed navigation season

James L. Wuebben

Prepared for
DETROIT DISTRICT
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From 1961 to 1970 navigation on the St. Marys River closed for the winter from mid-December to mid-April. Subsequent extension of the navigation season to include the winter months resulted in complaints of shoreline and dock damage along the navigation channels. Studies were initiated to examine the potential for navigation-caused damage, but information on damage during a navigation-free winter was lacking. Since limited navigation was planned during the 1979-80 winter, the St. Marys River System could be examined under relatively undisturbed conditions. The report examines potential navigation-related damage mechanisms

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and presents data from the closed navigation season. The results are compared with information collected during previous periods with winter navigation.

PREFACE

This report was prepared by James L. Wuebben, Research Hydraulic Engineer, Ice Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided by the Detroit District, U.S. Army Corps of Engineers under Agreement No. NCE-1A-80-035.

Field information on shore structure damage for the period of study was provided by John J. Gagnon, Engineering Aide, Ice Engineering Research Branch, CRREL. Dr. George R. Alger, water resources consultant, conducted the shore damage monitoring program.

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM Metric Practice Guide (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	By	To obtain
feet	0.3048*	metres
inches	0.0254*	metres
pound-force/inch^2 (psi)	6894.757	pascals

*Exact.

SHORELINE EROSION AND SHORE STRUCTURE DAMAGE ON THE ST. MARYS RIVER -- 1980 CLOSED NAVIGATION SEASON

by

James L. Wuebben

INTRODUCTION

From 1961 to 1970, navigation on the St. Marys River closed for the winter between 14 December and 11 January and reopened between 1 and 17 April. Subsequent extension of the navigation season beyond the traditional dates resulted in complaints of shoreline and dock damage along the navigation channels. Under the general authority of the Great Lakes and St. Lawrence Seaway Navigation Season Extension Study [Public Law 91-611, section 107(b)], studies of shoreline erosion and structure damage due to navigation in ice along the St. Marys River were undertaken.

One of the problems in determining the relative importance of navigation on shoreline erosion and dock damage has been the lack of information on damage during a navigation-free winter. Since limited navigation was planned during the 1979-80 winter, the St. Marys River system could be examined under relatively undisturbed conditions. The St. Marys River was ostensibly closed to navigation from 15 January to 24 March 1980. Actually the U.S. Coast Guard carried out some limited activities during that period, including seven trips by the icebreaker Katmai Bay and one trip by the icebreaker Mackinaw.

BACKGROUND

The degree to which the shorelines and shore structures of the St. Marys River are damaged by ice varies greatly according to the manner of ice action. In addition, there are several ways in which vessel passage can affect sediment transport and dock damage, including direct movement of ice in contact with vessels, propeller wash, wave action and other hydraulic effects.

Winter navigation, by disrupting the normal ice-cover characteristics, may aggravate any natural ice-related damage. Conversely, an ice cover may alter, and even amplify, the effects of navigation on system hydraulics and may influence any resulting damage. The significance of these various

effects depends on a number of local conditions, such as bathymetry, water level, soil conditions, ice conditions, shore and shore structure composition and geometry, and ambient water currents and waves.

Specific sites were studied during past navigation seasons to gain an understanding of the mechanics of the interaction between large-scale navigation and the hydraulics of a river system (Wuebben et al. 1978). This approach is required, since vessel-related effects consist of short periods of intense activity between long periods of relatively mild conditions. In addition, until recently few ships have operated through the entire winter, making it difficult to measure damage directly.

Hydraulic effects of ship passage

Although ship waves and other hydrodynamic effects of vessel passage have been studied in terms of vessel maneuverability and power requirements, they are not yet understood in terms of their effect on natural flow conditions and environmental factors. Information for periods of ice cover is almost nonexistent.

When a vessel is in motion, even in deep water, the water level in the vicinity of the ship is lowered, and the ship is lowered with it (this is called vessel squat). For the same ship, vessel squat increases as the vessel's speed increases or as the water gets shallower. When a ship enters shallow water, the flow patterns about the hull change. Water passing beneath the hull must pass faster than in deep water; as a result there is a pressure drop beneath the vessel, increasing vessel squat. If the channel is restricted laterally, this effect is exaggerated. These effects can occur independently when a channel is restricted either laterally or vertically and unrestricted in the other direction.

The movement of a ship in restricted waters causes another problem. The water level drop in the vicinity of the ship acts like a trough extending from the ship to the shore and moving along the river or channel at the same velocity as the ship. As the ship's speed increases, the moving trough deepens.

The phenomenon of nearshore drawdown and surge during vessel passage may be explained in terms of the moving trough. In sufficiently deep water the moving trough appears as a fluctuation in the elevation of the water surface. To an observer in a shallow or nearshore area where the depressed water level approaches or reaches the riverbed, it appears that

the water level recedes from the shoreline as the ship passes; this is followed by an uprush and finally a return to the normal level after the vessel-induced surface waves are damped. A more detailed discussion of this topic may be found in Wuebben et al. (1978).

Shore damage

The role of ice in sediment transport and shoreline erosion has many facets. The most obvious effect is that ice formed on a shore or riverbank may isolate and thereby protect the shore as shown in Figure 1. Ice formations can, however, cause significant localized damage by gouging ordinarily stable beach or bank formations and removing protective vegetation, by adfreezing sediment at the ice/soil interface, and by entraining sediment within the ice structure.

Another consideration is the effect of ice on the general hydraulics of a system. An ice cover on a river changes the open channel conditions into a form of closed conduit flow, changing the velocity profiles and distribution. The added boundary shear due to the ice cover decreases flow velocities and increases flow depth. Although there may be anomalies, the presence of an ice cover generally reduces sediment discharge. Ice jams, frazil dams or other ice irregularities that cause a constriction or deflection of flow may result in damage.

Figure 1. Early winter shore ice.

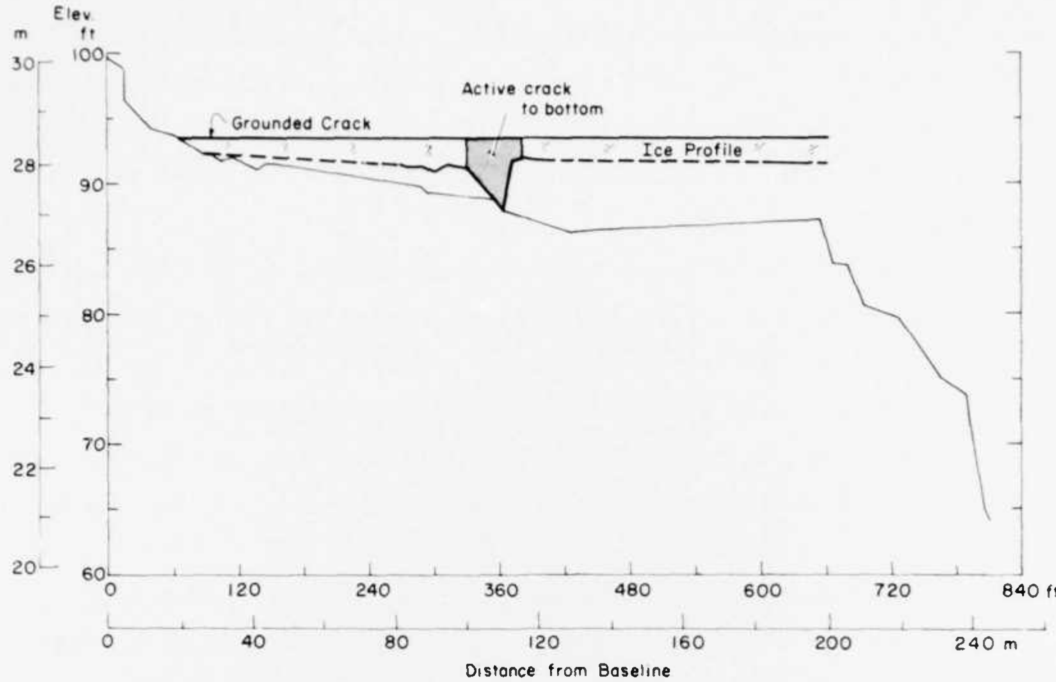


Figure 2. Active crack profile.

For sediment transport to occur, near-bottom water velocities must be sufficient to overcome a sediment particle's resistance to motion. These water velocities may be due to ambient river conditions, wind-driven waves, general turbulence, or ship-induced effects, among others, and they might be enhanced by channel configuration or ice irregularities. During vessel passage large and rapid changes in water velocity and direction can occur. More detailed discussions of this topic may be found in Wuebben et al. (1978) and Wuebben (1983).

During winter the passage of the moving trough can cause the ice cover to become grounded in shallow water and nearshore areas, and nearshore cracks in the ice may develop running roughly parallel to the water-depth contours. With recurring moderate water-level fluctuations, these hinge cracks do not completely refreeze and can provide an ice-movement relief mechanism. Continuing vertical and horizontal movement of the ice cover may cause the accumulation of ice debris (which resembles pressure ridges) at these active cracks. Depending on the characteristics of crack formation, ice dams extending to the river bed may develop at the cracks (Fig. 2).

Shore damage due to the lateral movement of ice induced by vessel passage is ordinarily small and is limited to early or unstable ice conditions and shore areas close to the navigation track. During spring breakup, larger, more massive ice floes may act on a shore, but with higher temperatures the ice is usually deteriorated and weaker.

Shore damage due to the horizontal movement of ice, while possibly significant, is unpredictable, infrequent, and difficult to quantify. A long length of shoreline may be affected over a period of years, but only a small portion might be affected in any one year. As a result, structural shore protection would be difficult to apply and most likely uneconomical. Regulating vessel traffic in affected areas under certain ice conditions may provide the best means of reducing damage.

Propeller wash, while sometimes a significant effect, is generally unaffected by the presence of ice. In addition, it is a fairly localized effect, and since this report deals primarily with nearshore effects it will not be considered here.

Wave action is the mode of action normally associated with ship-induced shoreline erosion. The waves produced by large-scale navigation are generally much smaller and less damaging than those produced by recreational craft, particularly when vessel speed and distance to the shore are considered. In addition, ice tends to damp out these waves.

Structural damage

Ice effects on structures tyically fall into one of the following categories:

1) Static ice forces, which arise from an ice sheet in contact with a structure subject to thermal expansion and contraction or steady wind or water drag forces.

2) Dynamic horizontal ice forces, which arise from ice sheets or floes that move against a structure due to water currents or wind.

3) Vertical ice forces, which arise from a change in water level and require the adhesion of floating ice to structures. For small structures in rivers such as the St. Marys, the dynamic horizontal and vertical forces are typically the critical modes of ice action.

Dynamic horizontal ice forces. Depending on the size and strength of an ice floe, the horizontal force exerted on a structure may depend on the strength of the ice sheet and its failure mode (bending, crushing or shear)

or the magnitude of the force driving the ice sheet (wind or water current). With a vertical pile or structure face, failure of the ice sheet usually occurs by crushing. Current Association of State Highway Transportation Officials standards employ a standard crushing strength for ice of 400 psi, while the current Canadian bridge design code provides for "effective ice strength" values ranging from 100 to 400 psi. Thus, if there is sufficient driving force for the ice sheet, a pile subjected to horizontal ice loads would have to be strong indeed.

Damage due to horizontal forces can occur naturally during the unstable early ice period or during spring breakup. Typically the midwinter ice on the St. Marys River is thick, and completely covers the water in most areas, so little horizontal movement takes place.

With winter navigation, however, there can be small, incremental movements of large ice masses. With the passage of a ship, drawdown tends to draw water away from the shore. It also pulls the ice cover slightly toward the channel. The following rise in water levels does not completely close the crack, and new ice can form in the crack. With repeated cycles, this mechanism can incrementally jack the ice cover toward the channel. If any cracks pass a structure, it can be pulled offshore. This has occurred so severely near Johnsons Point on the St. Marys River that the owner of one dock uses wire rope cables to help protect his structures from being pulled offshore.

Vertical ice forces. Another source of damage is the vertical movement of an ice sheet. On large bodies of water the water level responds to barometric pressure fluctuations, wind set-up, runoff, seiche action and possibly tidal motion. Local water-level fluctuations may also be caused by ship passage. These normal fluctuations are relatively harmless when there is no ice, but when an ice sheet is firmly attached to marine structures, they can exert large vertical forces through the floating ice cover.

Typically the structures that suffer the most damage are light-duty, pile-supported piers such as those used on the St. Marys River for pleasure boats. Designed for summer activity, the support piles have very little skin resistance to upward forces. With a rise in water level, the buoyant ice sheet lifts the pile from the soil and the void under the pile fills with soil. When the water level drops, the weight of the ice is supported by the skin friction and point bearing of the pile. Since the pile is not

driven into the soil as easily as it is pulled out, if the water level continues to drop, the ice will eventually break and the ice sheet will drop relative to the pile. When the temperature is below freezing, the ice adheres to the pile and breaks at some small distance away, leaving a collar of ice. The ice may then refreeze to the pile at a lower position. This process can gradually pull the pile completely out of the soil (Fig. 3). When the temperature is above freezing, the ice might instead slip along the pile surface and even abrade it, as shown by the wood shavings in Figure 4.

With moderate water-level fluctuations of sufficient frequency, cracks in the ice sheet around structures may not refreeze and a permanently open, active crack may result. This may serve as a vertical-force release mechanism. Thus, winter navigation may actually reduce damage if the ships pass frequently enough and generate only small water-level fluctuations (a few inches). If the crack passes through a dock (Fig. 5), if the ships pass infrequently so that the cracks may refreeze, or if the fluctuations are larger, this protective mechanism is lost.

If piles resist uplifting, the continuing water-level fluctuations may cause the ice to break about the pile, and a pile of ice rubble may develop. These piles can develop to the point where they damage the

Figure 3. Series of finger piers damaged by ice jacking.

Figure 4. Abrasion of wooden pile by ice motion. Note the wood shavings.

Figure 5. Active crack passing through dock.

Figure 6. Horizontal member of dock in contact with ice cover.

horizontal members of a dock. Docks can also be damaged if the water level is high enough so that the ice surface touches the cross members; then the ice forces act directly on the structure (Fig. 6).

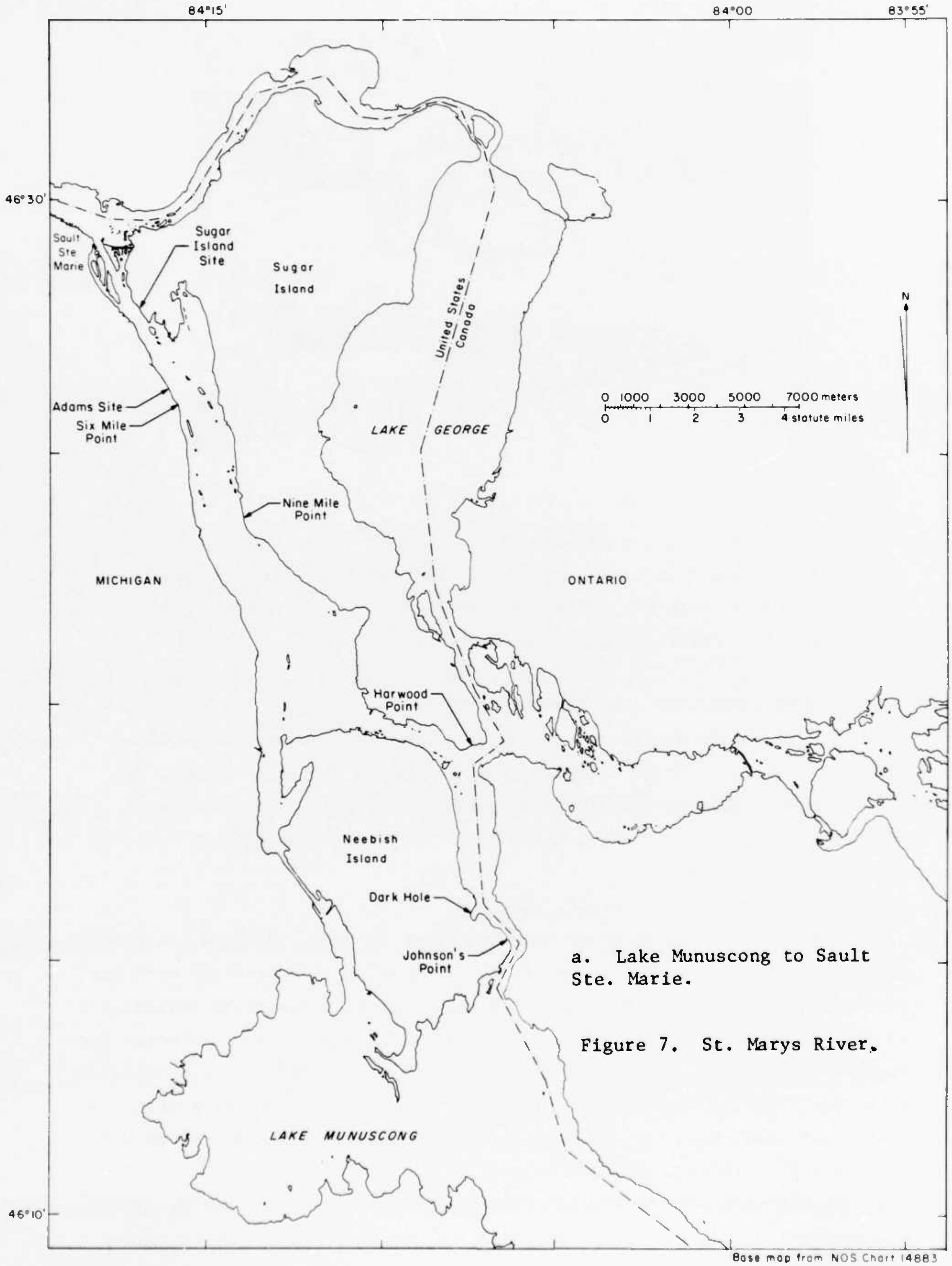
OBSERVATIONS DURING THE 1980 CLOSED SEASON

The shorelines and shore structures along the St. Marys River were monitored for ice-related damage during the closed navigation season of 1980. This period extended from 15 January to 24 March, with the only recorded vessel activity being seven trips by the USCG Katmai Bay and one by the USCG Mackinaw.

Sediment transport and shoreline erosion

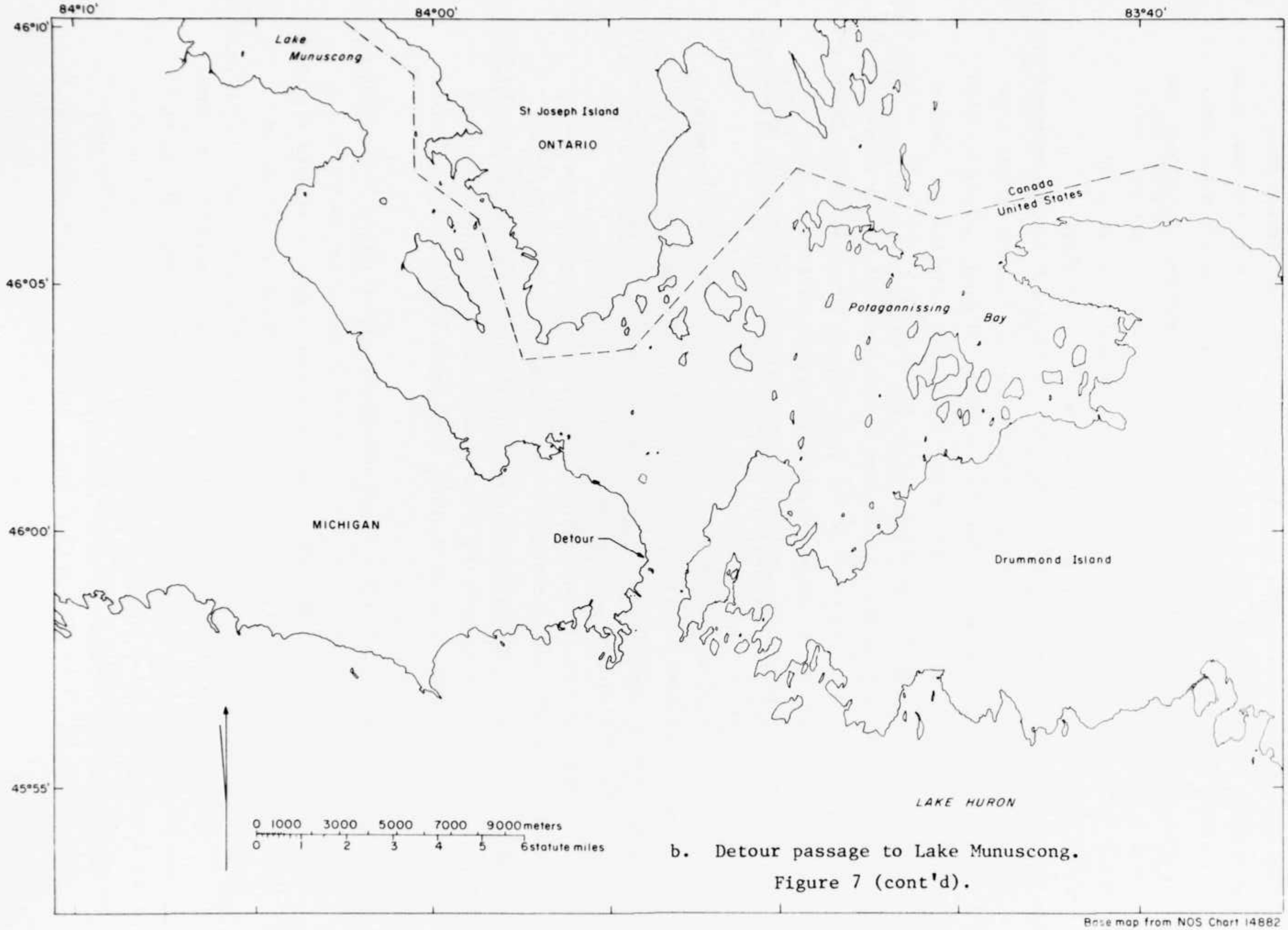
Various field measurements have been made by CRREL at sites along the St. Marys River since 1976 (Alger 1977, 1978, 1979), and previous work was conducted by the Detroit District, U.S. Army Corps of Engineers beginning in 1972 (U.S. Army Corps of Engineers 1974). Three sites were selected for further study during the closed navigation season of 1980; these sites are referred to as the Sugar Island site, the Adams site and the Nine Mile Point site (Fig. 7). The field study of shore damage for this report was conducted by a local consultant (Alger 1980).

Experience showed that measurements should include ice thickness profiles, river bottom profiles, and locations and patterns of active cracks.



a. Lake Munuscong to Sault Ste. Marie.

Figure 7. St. Marys River.



b. Detour passage to Lake Munuscong.

Figure 7 (cont'd).

Base lines, which are roughly parallel to the shore, had already been established at each site. Range lines extend from points on the base lines perpendicularly into the river. During periods of ice cover, holes were drilled through the ice along several range lines, and ice thicknesses and river bottom elevations were measured. Visible crack patterns were noted. River bottom elevations were also determined by wading the range lines using conventional survey equipment after the spring breakup.

Ice thickness profiles and active cracks. Ice thickness measurements are reported in Appendix A. In general, the ice was thinner farther from shore due to the faster water near the navigation channel. Also, although the river was ostensibly closed to winter navigation, limited ice-breaker activity occasionally disrupted the ice in the channel.

As Appendix A indicates, there were no active cracks at the Adams site and only a grounded shore crack at the Sugar Island Site. An active crack was evident on one of the ranges at the Nine Mile Point site on 31 January. Active cracks were common at all sites during previous years with winter navigation.

Nearshore bank and bottom profiles. Offshore bottom profiles were monitored at the same locations given for the ice thickness measurements. A comparison of these bottom elevations with data from previous years showed that no significant change had taken place.

Nearshore profiles were surveyed in May 1980 after navigation had resumed. Although local construction had altered the shore area at the Adams site in the past, measurements made in 1980 indicate that no further change had taken place. Several years of measurement (U.S. Army Corps of Engineers 1974; Alger 1977, 1978, 1979, 1980) show that no serious erosion is occurring at this site.

Nearshore profiles for the Sugar Island site are reported in Appendix B. Bank and bluff recession is evident at all of the range locations. This site has eroded in the past, which might have suggested effects due to winter navigation; however, these nearshore alterations have continued during a period with essentially no winter navigation.

Profiles measured at the Nine Mile Point site were compared with those reported in previous study periods (Alger 1977, 1978, 1979). The earlier measurements indicated no change, except for the shoreward migration of a small berm near Range 5. The results of this study, however, show nearshore change at all ranges except Range 3 (App. B). The area near Range 3

is protected with riprap and rock placed along the shoreline, and no nearshore alteration would be expected. Ranges 1, 2, 4, 6 and 7 all show some recession of the shore, while Range 5 indicates some filling due to the migration of the sand berm. Since water levels were high during the summer of 1979, erosive forces would have reached higher elevations on the shore and bluff than in the previous several years. No significant nearshore recession had been reported at Nine Mile Point during years with winter navigation, while some recession did occur during this period without winter navigation.

Dock damage

Docks were examined for ice-related damage along the entire length of the St. Marys River, but four areas were selected for monitoring based on a high potential for damage or where docks had been significantly damaged in the past. These areas were Six Mile Point, Dark Hole, Johnsons Point and Detour. Docks were visited just after the close of navigation; some damage was evident due to both horizontal and vertical ice forces. Since the study was designed to study damage during a period without navigation, the condition of the structures during the first field period were used as a basis for future comparisons. Subsequent observations were made monthly until spring breakup.

Six Mile Point. Six Mile Point is an area of significant damage potential due to navigation, but the structures are contructed better than most along the St. Marys River. The docks at LaPeers Marine Gulf Station consist of a main dock perpendicular to the shoreline, with eight finger piers extending from it parallel to the shore. This structure is surrounded by 12 pile clusters (Fig. 8).

Figures 9 and 10 were taken on 11 January 1980 just after navigation ceased. Figure 9 shows the active crack that can develop between the pile clusters at this site; the crack isolates the docks from vertical forces due to water-level fluctuations (including ship-induced fluctuations). Figure 10 shows some ice rubble due to horizontal movement of a thin, early ice sheet. Thus, pile clusters can help to protect a dock against both horizontal and vertical movements of the ice sheet. A change in water levels will still influence the ice about the dock (Fig. 11), but the effective area of the ice that develops the vertical force on the dock is smaller and the group action reduces the uplift force on any single pile.

Figure 8. Dock at Six Mile Point.

Figure 9. Active crack at pile cluster.

Figure 10. Ice rubble due to horizontal ice movement.

Figure 11. Ice collar on small dock piles.

Figure 12. Horizontal movement of ice against dock.

Thin ice or small floes may still move horizontally against a dock (Fig. 12), but due to their limited size, forces are reduced. The docks at Six Mile Point were monitored throughout the closed navigation season, and although modes of ice action similar to those during periods with navigation were evident, no perceptible damage was observed.

Dark Hole, Neebish Island. Another site monitored during the closed navigation season was the area known as the Dark Hole on Neebish Island. During previous years the Franklin Resort dock suffered significant damage due to uplifting forces (Figs. 13 and 14).

Prior to the 1978-79 winter navigation season, the Corps of Engineers had two demonstration docks installed at this site. One was a rock-filled timber crib (Figs. 15 and 16). The other was a pile-supported structure, with pile surfaces of various materials ranging from wood to plastic to steel (Fig. 17). Both of these structures stood up very well during both winters they were in place. The original Franklin Resort dock, which can be seen on the left side of Figure 15, was repaired and experienced no perceptible damage during the winter of 1980.

Johnson's Point. Another site that has suffered significant damage during previous winter navigation seasons is the Little Neebish Resort just upstream from Johnson's Point on Neebish Island. Figure 18 is an aerial

Figure 13. Franklin Resort Dock, end view (1976-77 winter).

Figure 14. Franklin Resort Dock, side view (1976-77 winter).

Figure 15. Dark Hole timber crib.

Figure 16. Timber crib close-up.

Figure 17. Dark Hole pile dock.

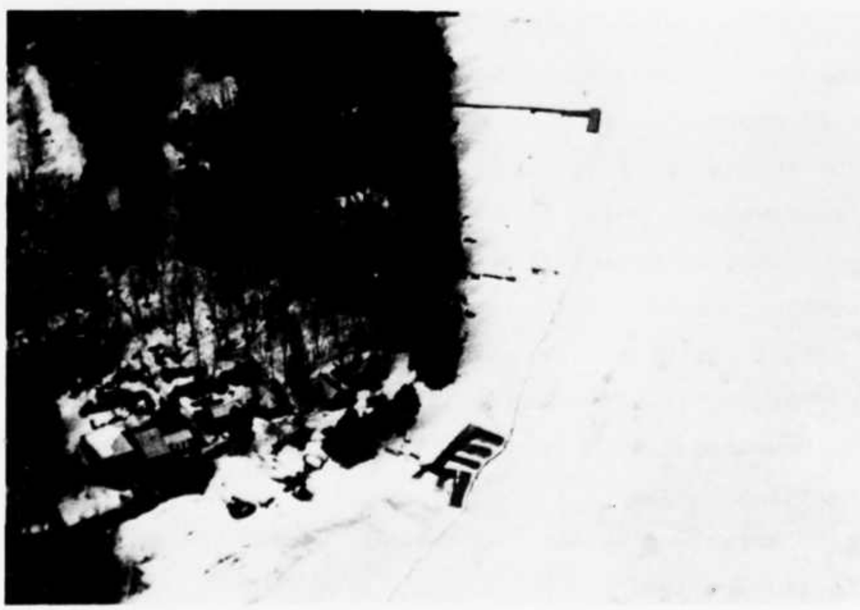


Figure 18. Aerial view of Johnsons Point.

Figure 19. Spreading of finger piers by ice action.

veiw of the area during the 1977 navigation season and shows a large shore-parallel active crack passing just offshore of the structure. Other cracks passed through the structure that year, spreading the finger piers (Figs. 18 and 19).

During the 1980 closed navigation season these cracks were not evident. Figure 20 shows conditions several weeks after the close of navigation. The dock shown in Figure 20 had been uplifted before the close of navigation and did not change during the closed period (Fig. 21).

Figure 22 shows the docks at the Little Neebish Resort during spring breakup. The left side of the structure in this picture is another Corps of Engineers structure, which is supported on piles of various composition. It sustained no perceptible damage throughout the winter. The large, floating ice masses were prevented from flowing against the docks by an area of intact shorefast ice upstream (Fig. 23).

Detour. Figure 24 shows the condition of a series of small docks near the mainland Drummond Island Ferry dock on 25 February 1980. Some uplift is apparent, but as shown in Figure 25 taken on 15 March 1980 near the end of the closed navigation season, no further damage was apparent through the closed navigation period.

Another nearby dock (referred to as the Lake Carriers Dock) is shown in Figures 26 and 27. Figure 26 was taken on 25 January 1980 while Figure 27 was from 15 March 1980. There was no perceptible damage to this portion

Figure 20. Little Neebish Resort at beginning of closed navigation season.

Figure 21. Little Neebish Resort with navigation re-opened.

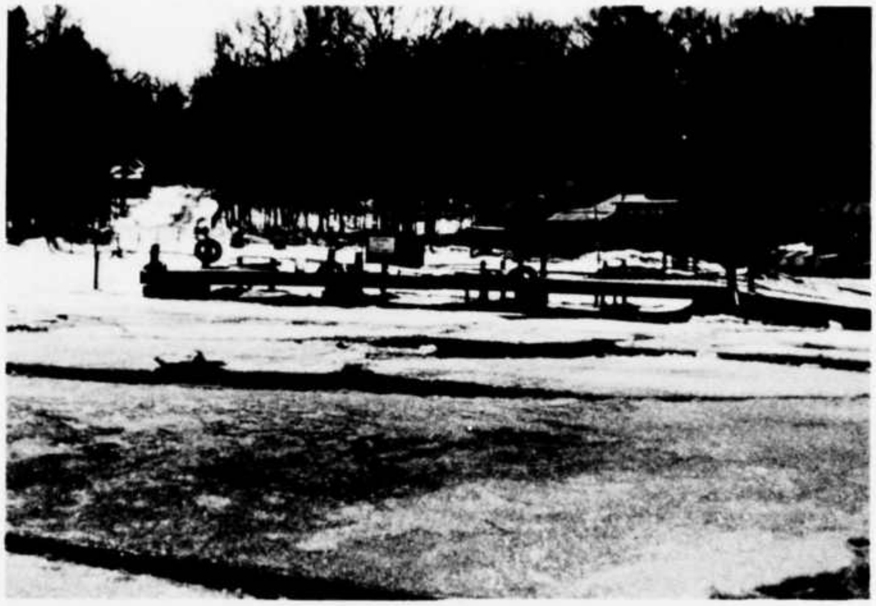


Figure 22. Little Neebish Resort during spring break-up. Note the large floating ice masses in the foreground.

Figure 23. Shore-fast ice and tire boom at Little Neebish Resort. The tire boom was another Corps of Engineers project in 1978-79 to control ice.

Figure 24. Small dock at Detour after close of navigation.

Figure 25. Small dock at Detour near opening of navigation.

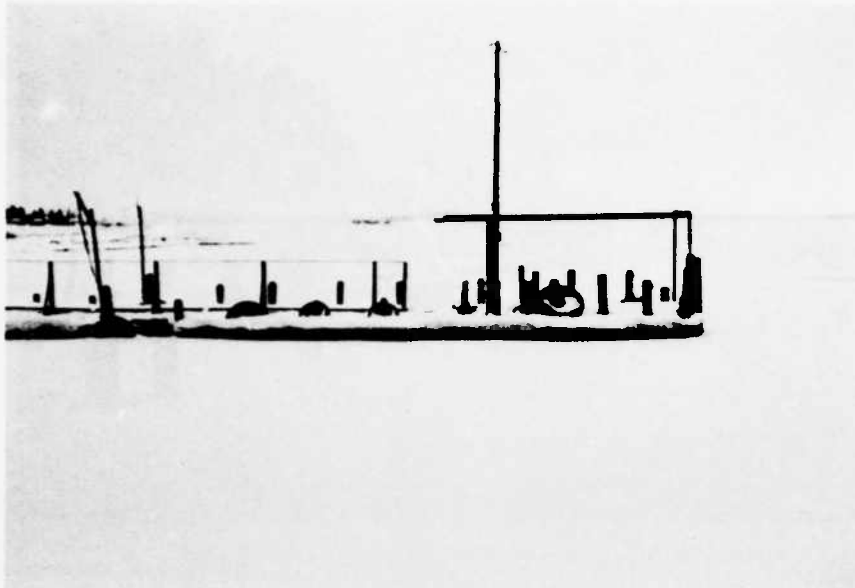


Figure 26. Lake Carriers dock after close of navigation.

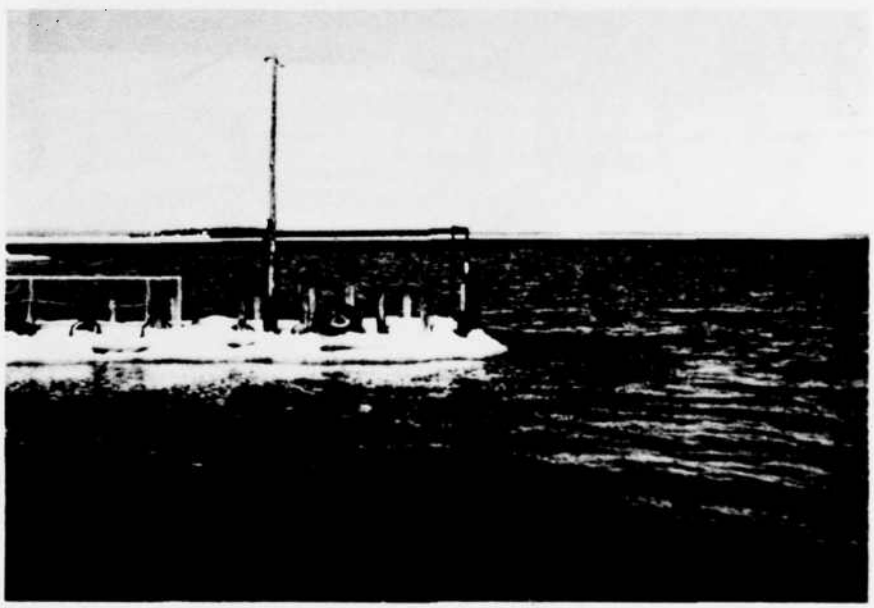


Figure 27. Lake Carriers dock near reopening of navigation.

Figure 28. Damaged Lake Carriers dock with fishing boat.

Figure 29. Damaged Lake Carriers dock near opening of navigation.

of the dock. Figure 28 shows another portion of this same facility on 25 January 1980; this part had sustained some damage due to horizontal forces (possibly ice) prior to the closed navigation season. Figure 29 shows the same structure on 15 March 1980 near ice out with no further apparent damage.

CONCLUSIONS AND RECOMMENDATIONS

It is evident from the information reported here and from similar data from previous years that nearshore bottom and bluff recession continues at sites that have previously been reported as active. However, one site, which previously was relatively inactive, now shows some erosion. Since very little navigation took place during the winter of 1980 but navigation was active during previous periods of study, the conflicting results indicate only that the available information is inadequate to quantify ship-induced damage. If erosive forces due to winter navigation are present, they can only be identified by a more intensive year-round study. If a future monitoring program is established, the frequency of observations should be increased substantially.

Although some docks had been damaged before the beginning of the closed navigation period, none of the monitored docks were damaged during the period of study. The greatest damage usually occurs when the ice is from 0 to 6 inches thick. Since this range was surpassed before the close of navigation, damage that occurred during this critical period could not be addressed. In addition, spring breakup occurred after navigation was resumed.

Another topic that should be studied is the effect of winter navigation on ice production. Continuing icebreaking by vessels and subsequent refreezing can increase the amount of ice in the river. In addition, the horizontal jacking of the ice cover towards the channel can increase the quantity of ice. This added ice can substantially affect water levels and flow velocities in the river, which in turn can affect the magnitude of vessel effects.

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APPENDIX A: ICE THICKNESS AND CRACK PATTERNS

Table A1. Ice thickness and crack patterns at Adams site, Range B (Alger 1980).

Distance (ft)	Ice thickness (ft) 1/31/80	2/26/80	3/29/80
100	0.7	1.3	Grounded shore ice to a distance of 20 feet offshore. Some drifting pans offshore of the fast ice.
150	0.7	1.2	
160	0.7	1.2	
180	0.8	1.3	
200	0.7	1.2	
220	0.9	1.3	
240	0.9	1.3	
260	0.9	1.1	
270	0.9	1.3	
280	0.8	1.0	
290	0.9	1.2	
300	0.9	1.3	
320	0.9	1.0	
340	0.9	0.9	
360	0.7	0.8	
380	0.9	0.8	
400	---	0.6	
420	---	0.6	

Notes: 1/31/80 - No active parallel shore cracks; clear black ice; 2 inches of snow on ice. 2/26/80 - 6 inches of snow on ice.

Table A2. Ice thickness and crack patterns at Adams site, Range E (Alger 1980).

Distance (ft)	Ice thickness (ft) 1/31/80	2/26/80	3/39/80
200	0.8	1.3	Grounded shore ice to a distance of 20 feet offshore. Some drifting pans offshore of the fast ice.
250	0.7	1.3	
300	0.7	1.1	
310	0.8	1.2	
320	0.9	1.2	
330	0.9	1.2	
340	0.8	1.2	
350	0.9	1.1	
400	0.9	1.0	
450	0.9	0.9 (slush on ice)	
500	0.9	---	

Notes: 1/31/80 - No active parallel shore cracks; clear black ice; 2 inches of snow on ice. 2/26/80 - 6 inches of snow on ice.

Table A3. Ice thickness and crack patterns at Adams site, Range J (Alger 1980).

Distance (ft)	Ice thickness (ft) 1/31/80	2/26/80	3/29/80
200	0.9	1.3	Grounded shore ice to a distance of 20 feet offshore. Some drifting pans offshore of the fast ice.
250	0.8	1.3	
300	0.8	1.3	
320	0.9	1.2	
340	0.8	1.2	
360	0.8	1.2	
380	0.8	1.2	
400	0.8	1.2	
450	0.9	0.9 (slush on ice)	

Notes: 1/31/80 - No active parallel shore cracks; clear black ice; 2 inches of snow on ice. 2/26/80 - 6 inches of snow on ice.

Table A4. Ice thickness and crack patterns at Sugar Island site, Range O (Alger 1980).

Distance (ft)	Ice thickness (ft) 1/31/80	2/26/80	3/29/80
100	0.8	Open water to shore.	Open water to shore.
200	0.8		
250	0.8		
300	0.6 (some brash		
320	1.0 and snow ice)		
340	0.7 "		
360	0.8 "		
380	0.6 "		
400	0.7 "		

Notes: 2/1/80 - 2 inches of snow on ice; nonparallel cracks offshore; active, parallel shore crack 20 feet out from base of bluff.

Table A5. Ice thickness and crack patterns at Sugar Island site, Range 7 (Alger 1980).

Distance (ft)	Ice thickness (ft)		
	1/31/80	2/26/80	3/29/80
100	0.8	Open water to shore.	Open water to shore.
150	0.8		
200	0.8		
220	0.8		
240	0.4 (brash)		

Note: 2/1/80 - 2 inches of snow on ice; nonparallel cracks offshore; active, parallel shore crack 20 feet out from base of bluff.

Table A6. Ice thickness and crack patterns at Sugar Island site, Range 15 (Alger 1980).

Distance (ft)	Ice thickness (ft)		
	1/31/80	2/26/80	3/29/80
100	0.4	Open water to shore.	Open water to shore.
120	0.6		
140	0.6		
160	0.8 (brash)		
unsafe			

Note: 2/1/80 - 2 inches of snow on ice; nonparallel cracks offshore; active, parallel shore crack 20 feet out from base of bluff.

Table A7. Ice thickness and crack patterns at Nine Mile site, Range 2 (Alger 1980).

Distance (ft)	Ice thickness (ft) 1/31/80	2/26/80	3/29/80
100	1.0	1.5	Grounded shore ice sheet for a distance of approximately 100 feet out from shore.
200	0.9	1.3	
300	1.0	1.3	
400	1.0	1.3	
500	1.0	1.3	
560	1.1	1.1	
580	0.9	1.1	
590	active crack	---	
600	0.8	0.8	

Note: 1/31/80 - 2 inches of snow on ice; evidence of snow-covered broken pans along entire Nine Mile location (both ends) about 200-300 feet offshore. 2/27/80 - No active cracks.

Table A8. Ice thickness and crack patterns at Nine Mile site, Range 7 (Alger 1980).

Distance (ft)	Ice thickness (ft) 1/31/80	2/26/80	3/29/80
100	1.3	1.9	Grounded shore ice sheet for a distance of approximately 100 feet out from shore.
150	1.1	1.6	
200	1.0	1.5	
220	1.0	1.6	
240	1.0	1.4	
260	1.0	1.4	
280	1.1	1.4	
300	1.0	1.4	
370	1.0	1.3	

Note: 1/31/80 - 2 inches of snow on ice; evidence of snow-covered broken pans along entire Nine Mile location (both ends) about 200-300 feet offshore. 2/27/80 - No active cracks.

APPENDIX B: SHORE PROFILES

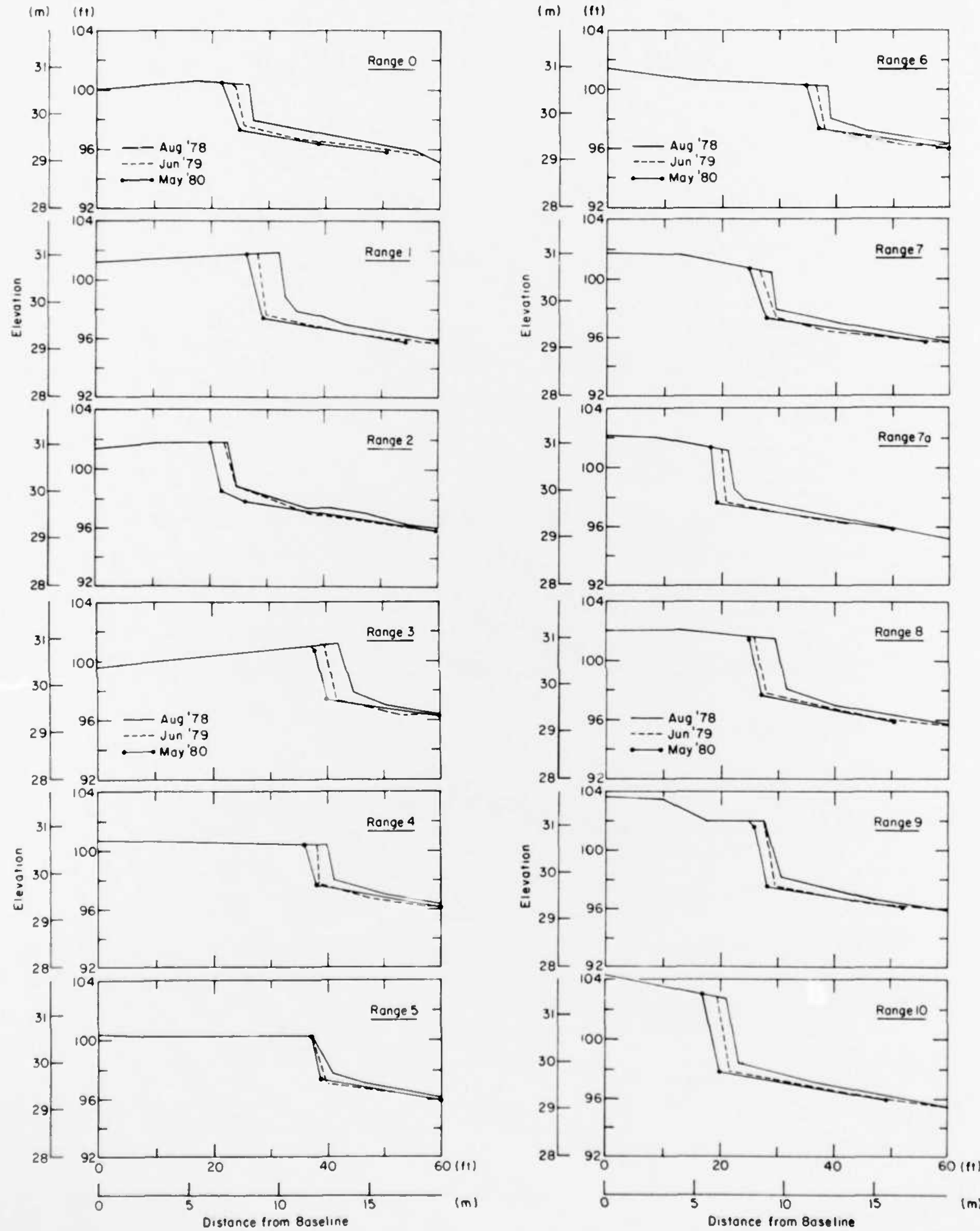


Figure B1. Shore profiles at Sugar Island site.

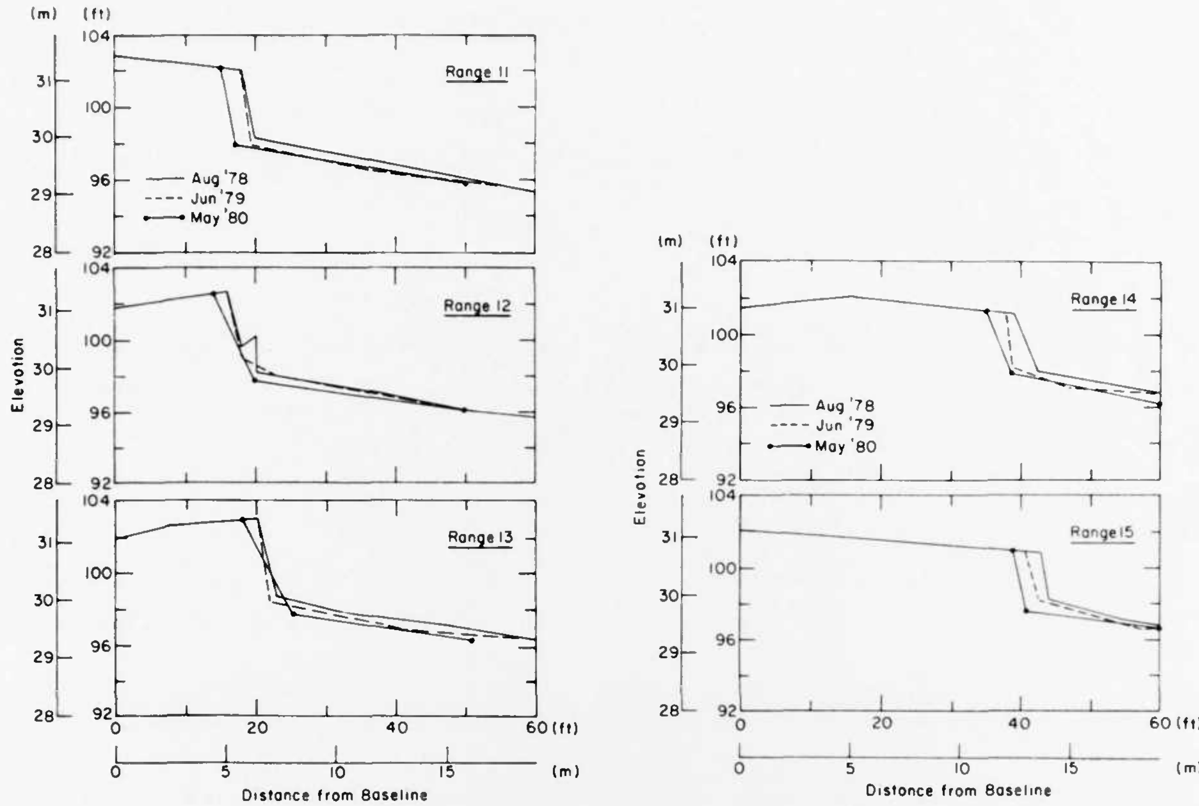


Figure B1 (cont'd). Shore profiles at Sugar Island site.

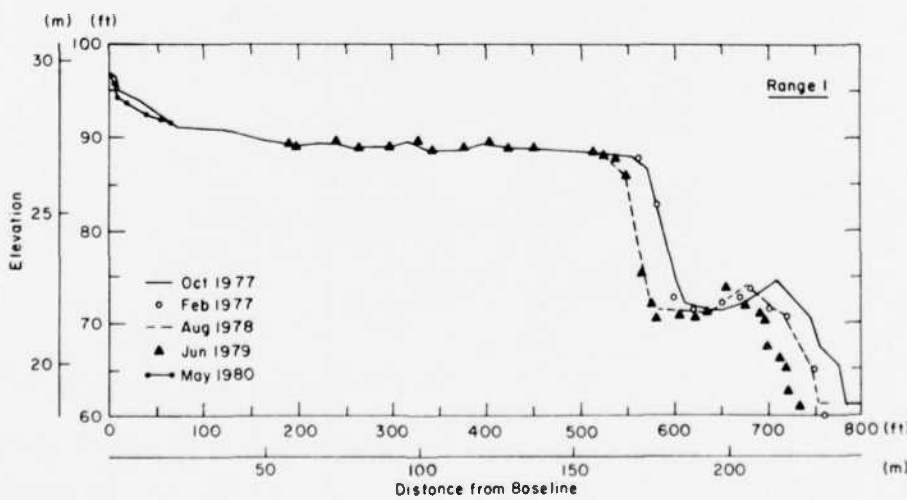


Figure B2. Shore profiles at Nine Mile Point.

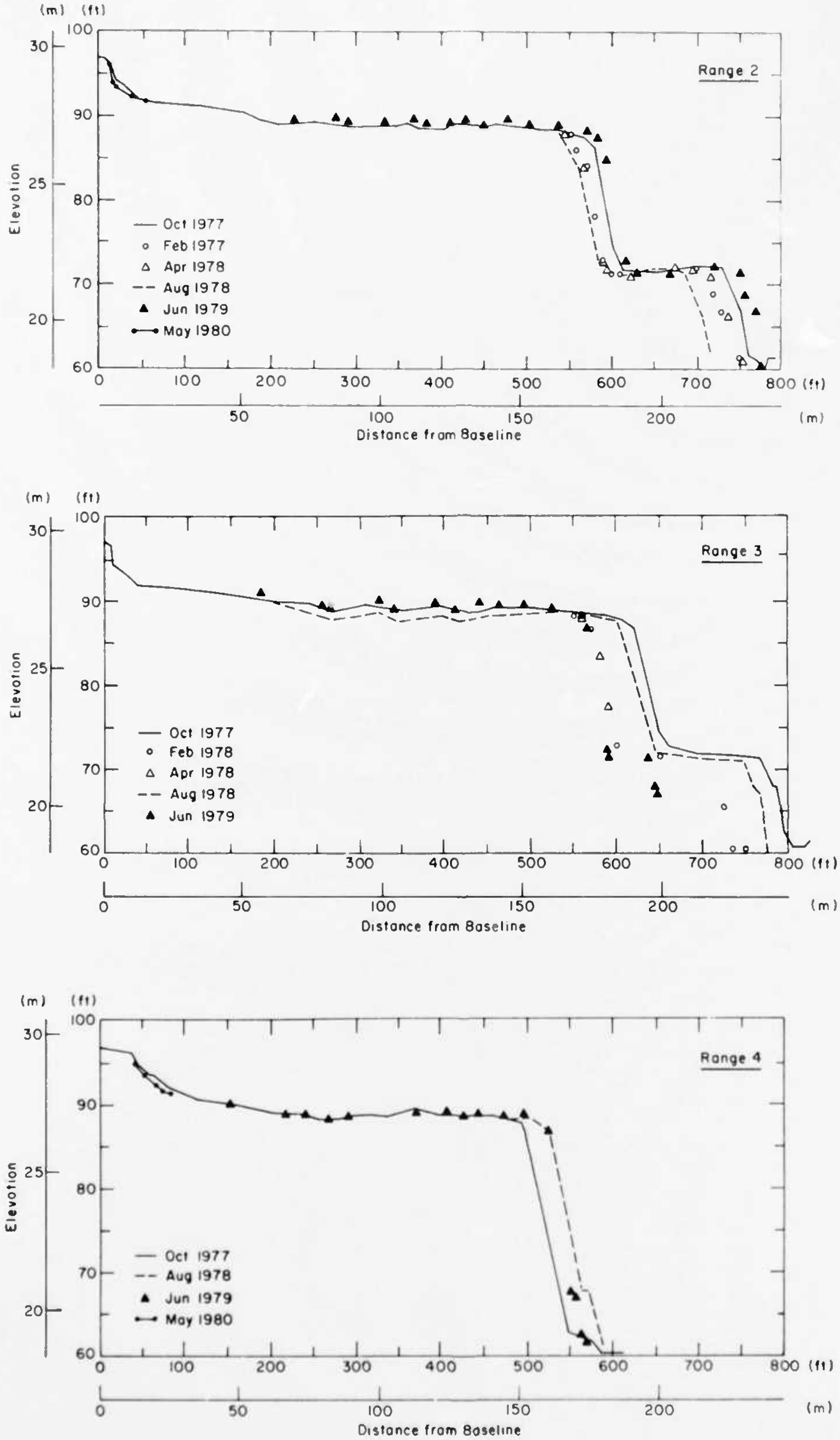
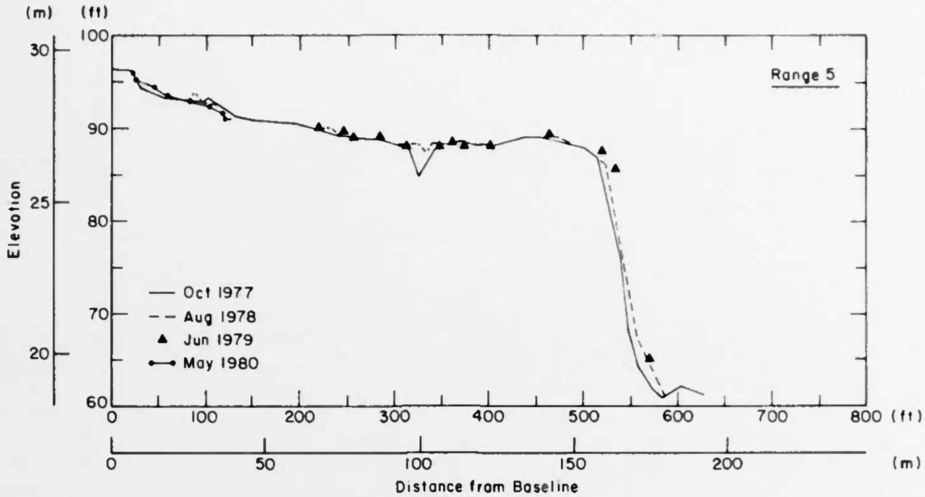
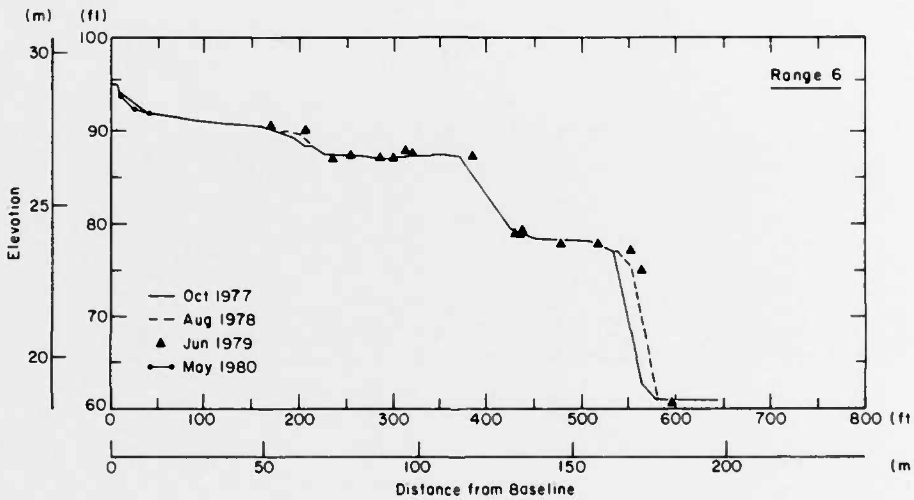


Figure B2 (cont'd).





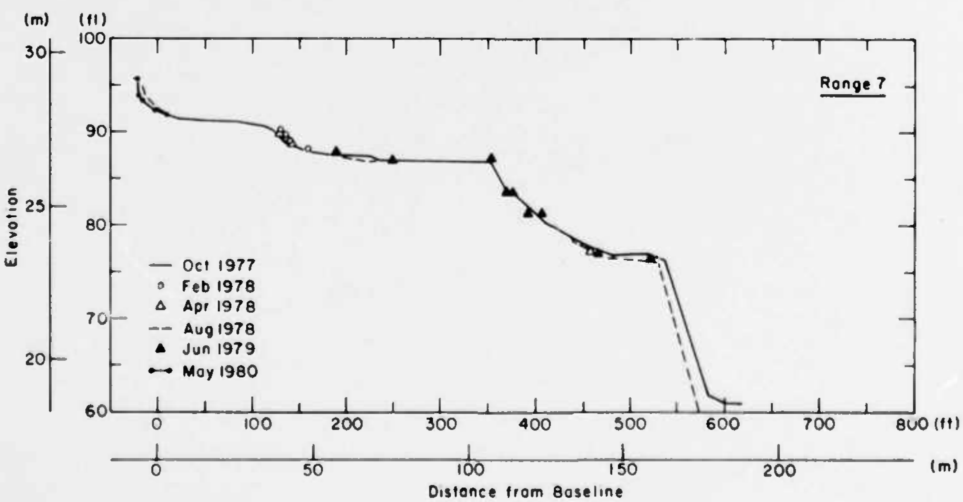


Figure B2 (cont'd). Shore profiles at Nine Mile Point.

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